U.S.D.A. Forest Service Research Paper SE-36 June 196

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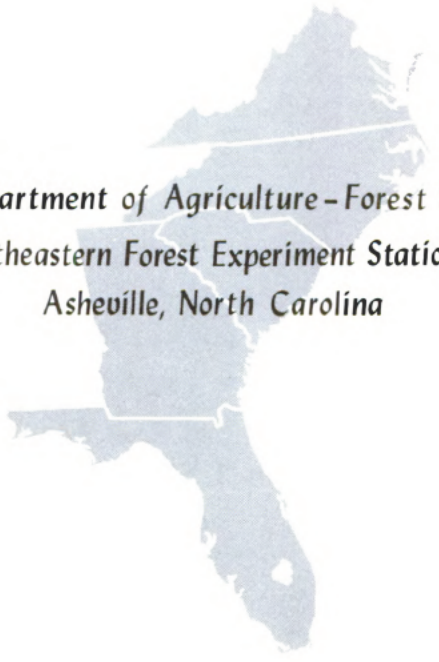

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Asheville, North Carolina

Fuel Consumption and Fire Behavior of Hazard Reduction Burns

by

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Prescribed burning has been used by many forest managers in the Southern Coastal Plains as a tool for fire hazard reduction. The general weather requirements for this type of burning have been recognized,[1] but the exact results of prescription burns applied under specific environmental conditions are not known. Forest managers must be able to predict how the environment will influence fuel consumption, heat release, and rate of spread if the fires are to meet the objectives of the prescription.

The purpose of this study was to measure fuel consumption and fire behavior of hazard reduction burns under a variety of environmental conditions.

MATERIALS AND METHODS

Prescribed burns were conducted on the Waycross State Forest in the Coastal Plain of Georgia. The timber type of the area was slash-longleaf pine with a typical understory of palmetto-gallberry. This understory had not been burned for more than 10 years. The stand averaged 50 feet in height with a basal area of 53 square feet per acre. The dry weight of the litter ranged from 4.5 to 16 tons per acre, and the dry weight of the vegetative fuel in the understory ranged from 2.5 to 3.5 tons per acre.

The plots were 2.5 to 3.5 chains square, separated by plowed firelines. Individual plots were burned over a 3-year period--in March 1959, February and March 1960, and January and February 1961. Backfires and head fires were tested in 1959 and 1960 and backfires only in 1961. Night burns were made in 1959 but not in 1960 and 1961.

Each plot was documented with respect to weather conditions at the time of burning, fuel conditions before and after burning, and the characteristics of the fire itself. Data on fuel weight and moisture content of the forest floor were obtained from square-foot samples of upper or

[1] Dixon, Merlin J. A guide to fire by prescription. U. S. Dep. Agr., Forest Serv., South. Reg., 32 pp. 1965.

Figure 1.--Model of a forest litter bed showing layers sampled for moisture content and weight.

fresh needle litter, middle or weathered litter, and lower or decomposed litter (fig. 1). Weight and moisture content of live vegetative fuel were measured on 1/4-milacre samples for each fire.

Percentages of fuel reduction were calculated from weight measurements taken before and after burning (fig. 2). Fuel energy was calculated for each litter layer by first multiplying the weight loss of each layer by its low caloric value.[2] This gross value was then corrected for estimated heat losses due to radiation, incomplete combustion, and fuel moisture content. The resulting value was an estimate of the available fuel energy of the litter in B.t.u. per square foot. Rate of fire spread times available fuel energy gave the value of fire intensity.

An analysis of variance was made of the percentages of fuel reduction; multiple regression analyses were made to relate fuel and environmental variables with litter reduction, available fuel energy, and rate of spread.

RESULTS AND DISCUSSION

Total fuel reduction based on 16 test burns was found to be very similar for backfires and head fires, averaging 56 percent and 55 percent, respectively. Backfires, however, consumed more litter fuel (58 vs. 49 percent) and less vegetative fuel (53 vs. 61 percent) than did head fires. Backfires spread slowly and burn deeper into the litter layers, whereas head fires spread rapidly and often burn only the upper litter layer. This reaction has also occurred in laboratory test fires.[3]

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[2]Hough, W. A. Caloric value of some common forest fuels of the southeastern United States. 8 pp. 1967. (Final report on file at Southern Forest Fire Laboratory, Macon, Ga.)

[3]Beaufait, William R. Characteristics of backfires and headfires in a pine needle fuel bed. Intermountain Forest and Range Exp. Sta., U. S. Forest Serv. Res. Note INT-39, 7 pp. 1965.

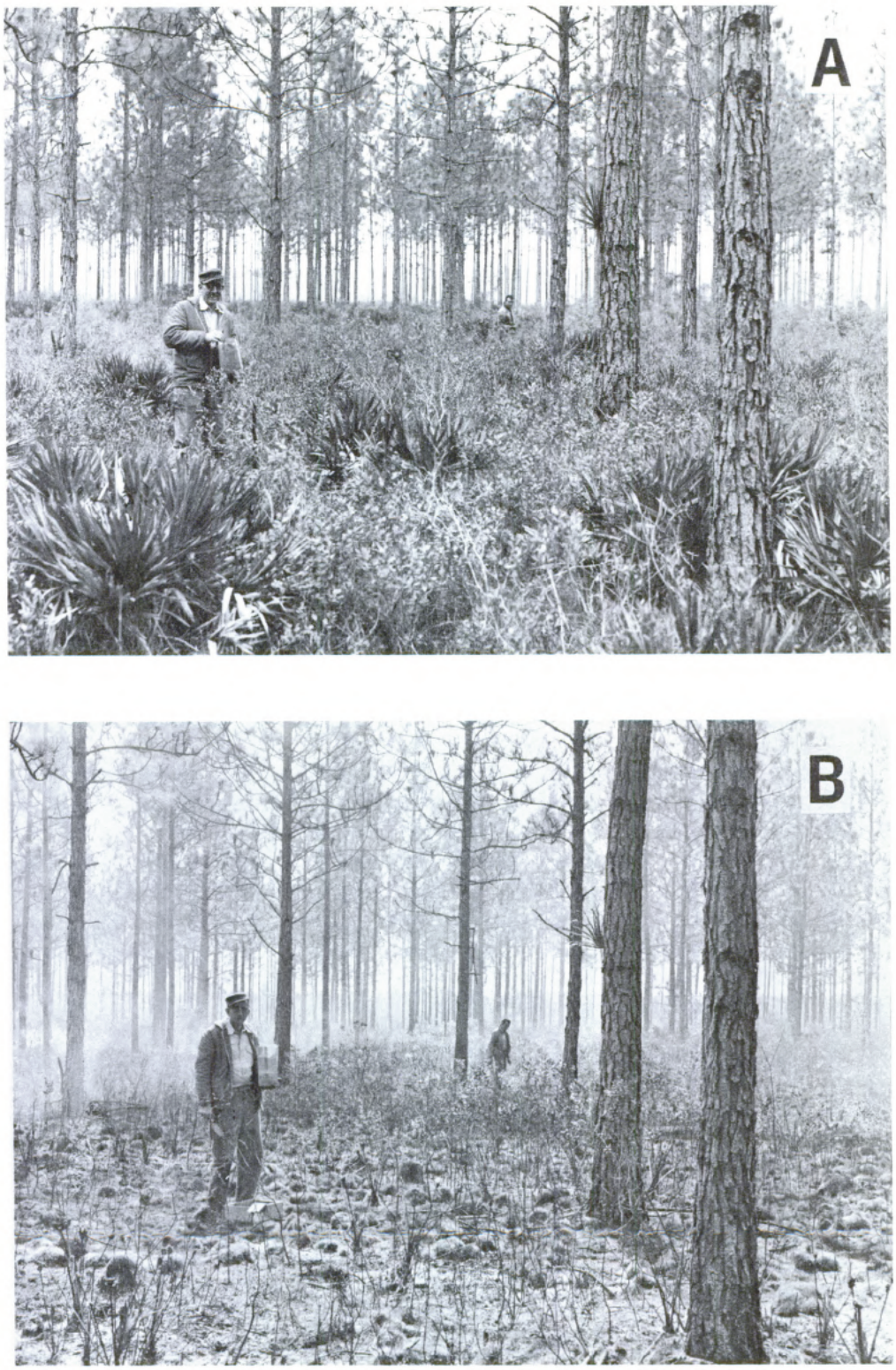

Figure 2.--Fuel samples were collected on the same plot both (A) before and (B) after a hazard reduction burn to determine their loss in weight as a result of the fire.

Because the low flames of a backfire lean away from unburned fuel, little preheating of standing vegetation occurs and consumption rates in the aerial fuel portions may be low. In a head fire, however, standing vegetation is exposed to considerable preheating and higher flames that consume greater amounts of fuel.

Anaylsis of 37 daytime backfires showed significant differences in total fuel reduction according to year. These differences were due to low consumption on some 1959 test burns where water was evident on the plot surface. A significant difference in reduction between morning and afternoon burns was also shown; afternoon burns resulted in greater fuel consumption, undoubtedly because of the lower relative humidities and fuel moistures during those hours.

Release of available fuel energy (AFE) was computed for individual litter layers. About 30 percent of this energy was produced by combustion of the fresh needles, 46 percent by combustion of the weathered layer, and only 24 percent by combustion of the decomposed layer. The fresh and weathered layers made up only half of the total litter weight and yet produced three-fourths of the available fuel energy. The greater consumption of these layers undoubtedly resulted from their lower moisture contents. Another factor in this uneven consumption was the greater availability of oxygen in the loosely packed upper layers than in the more compact decomposed layer.

Litter Consumption and Energy Release

Regression analyses showed that the dry weight and the percent moisture content of the total litter layer could be used to predict percent of litter consumed and amount of energy released by a backfire. Calculated values of litter reduction and energy release as a function of these variables are plotted in figure 3. For these test burns, fires producing more than 2,000 B.t.u. per square foot were generally found to be damaging to pine overstories, whereas those below 800 B.t.u. per square foot usually did not consume enough fuel for effective hazard reduction. These values, therefore, were used as limits on the graph.

Release of available fuel energy from the litter layer was directly related to weight and inversely related to moisture content. As fuel moisture drops, less energy is needed to drive off water, more fuel is burned, and more energy released. A decrease in litter weight resulted in a decrease in energy release (even though percent reduction increased) because less fuel was actually burned.

Vegetative Reduction and Energy Release

Vegetative fuel reduction was very erratic for some species and was not related to litter reduction; therefore, only average reduction data are mentioned here. Reduction of wiregrass fuel was complete each time the fire burned through the sample area. The moisture content of the average wiregrass sample was 56 percent, and the weight burned was 55 grams per square foot. This weight indicates an energy release of about 550 B.t.u. per square foot.

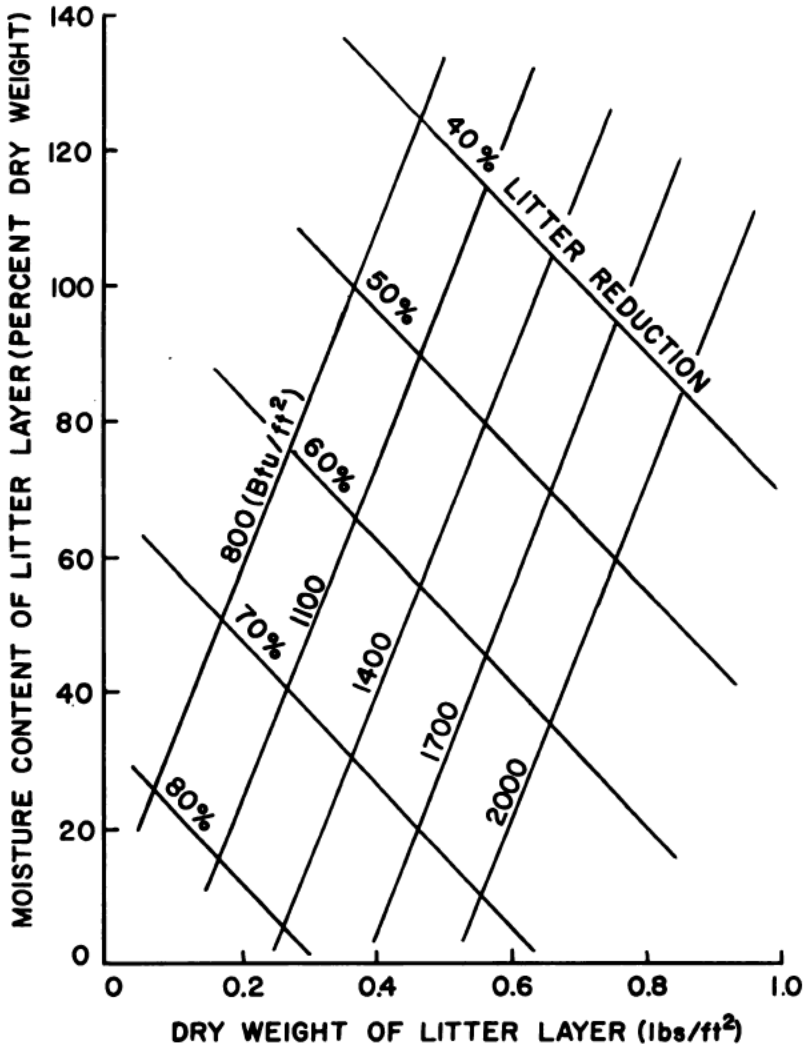

Figure 3.--Estimated litter reduction and release of available fuel energy (AFE) produced by backfires in the Coastal Plain.

Gallberry fuel reduction ranged between 0 and 70 percent. On sample plots showing no reduction, field observation indicated that backfires burned under the plants and only scorched the leaves. The moisture content of the average gallberry sample was 84 percent, fuel reduction was 38 percent, and the weight burned was 12 grams per square foot. This consumption would add about 135 B.t.u. per square foot to available energy.

Palmetto reduction was significantly related to moisture content of the plant. As moisture content increased, consumption decreased. The relationship was not strong enough, however, to serve as a basis for accurately predicting palmetto reduction. Average moisture content of the palmetto samples for the 3 test years was 123 percent, with a fuel reduction of 62 percent. The burned fuel weighed 40 grams per square foot on the average and released 395 B.t.u. of energy per square foot.

Because the reduction of vegetative material proved difficult to predict quantitatively from environmental-fuel variables, the ability to predict litter reduction rather precisely may be quite important in estimating energy release. The contribution of vegetative fuel, nevertheless, cannot be ignored. In this study, the contribution of vegetation to heat energy release amounted to about 100 to 500 B.t.u. per square foot, depending on the specific fuel involved. This heat release was in addition to the 800 to 2,000 B.t.u. per square foot produced through combustion of the litter layer.

Rate of Spread

Analysis of data on rate of spread of backfires indicated that this rate had no significant relationship to the dry weight or the moisture content of the whole litter layer. Regression analyses incorporating moisture data from individual layers of litter, however, indicated that these moisture contents were significantly related to rate of spread.

As was expected, moisture of the fresh litter was significantly related to relative humidity and the number of days since at least one-quarter inch of rain. This relationship served as a means of predicting the rate of spread of backfires (fig. 4). Either moisture content of the fresh litter or days since rain could be used with relative humidity to predict rate of spread. For example, if relative humidity measures 50 percent and 3 days have elapsed since rain, backfire spread should average about 1.6 feet per minute. Moisture content of the fresh litter should be about 27 percent under these conditions. In cases where it is difficult or impossible to gauge the number of days since rain, a direct measurement of the moisture of the fresh litter would be necessary in order to predict rate of spread of the backfire. For example, if the moisture content measured 15 percent and the relative humidity was 30 percent, backfire spread should average about 2.4 feet per minute.

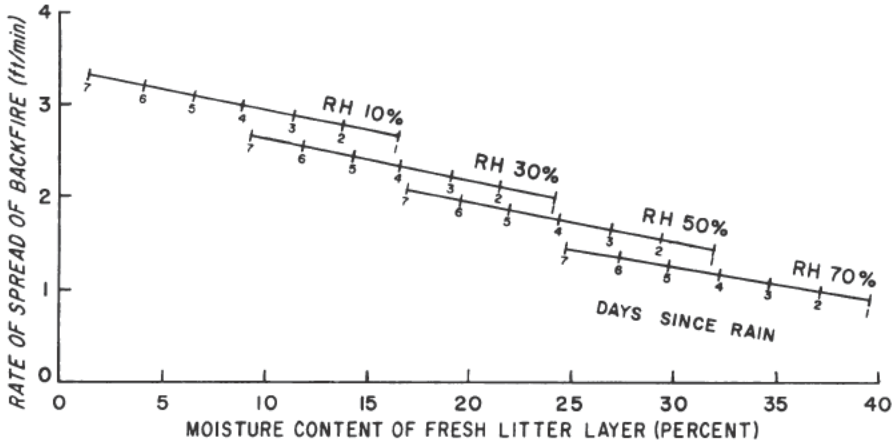

Figure 4.--Rate of spread of backfires is a function of relative humidity, adjusted for either moisture content of the fresh litter layer or the number of days since one-quarter inch or more of rain.

Rate of spread of backfires did not change for wind speeds between 0 and 8 m.p.h. (measured in the stand at eye level). The same uniformity was noted in laboratory crib fires[4] and in needle bed burns (see footnote 3).

Fire Intensity

Fire intensity may be calculated from the equation

$$I = Er$$

where E is the available fuel energy and r is rate of spread.[5] Intensity values computed from values of available energy and rate of spread for each backfire ranged from 5 to 124 B.t.u. per second per foot.

Byram[5] states that for prescribed fires burning into the wind, intensities probably range from 19 to 58 B.t.u. per second per foot. The estimated intensities of approximately one-third of the test burns made during this study fall outside Byram's range. It appears from observations conducted during the study that a wide range in backfire intensities, possibly from 20 up to 90 or 100 B.t.u. per second per foot, will give satisfactory results. Unwanted damage to the timber stand may occur if intensities rise above this limit, especially if wind speeds are low.

SUMMARY

Hazard reduction burns were conducted over a 3-year period in the Georgia Coastal Plain. Information was collected on the influence of fuel and weather variables on fuel consumption and energy release.

Results indicate that the percent of litter reduction and the output of fuel energy from backfires in litter fuel may be estimated from the dry weight and the moisture content of the total litter layer. It was also found that 76 percent of the total available fuel energy was released from the fresh and weathered litter layers, which made up only 50 percent of the dry weight of the total litter.

Rate of spread of backfires was found to be inversely related to the moisture content of the fresh litter layer. Relative humidity and days since measurable rain may be used to predict the moisture content of the fresh litter or rate of spread. Wind was not related to spread of backfires in these tests.

Fire intensities were estimated from available fuel energy and rate of spread. Data from these burns indicate that fuel consumption will be poor if intensities fall below 20 B.t.u. per second per foot, whereas intensities of 90 B.t.u. or above will damage the timber stand.

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[4]Byram, G. M., Clements, H. B., Bishop, M. E., and Nelson, R. M., Jr. Final report project fire model - an experimental study of model fires. U. S. Forest Serv. Southeast. Forest Exp. Sta., 51 pp. 1966.

[5]Byram, G. M. Combustion of forest fuels. In Forest fire: control and use, by K. P. Davis. Chapter 3, pp. 61-89. 1959.